Paper N° C 004565
Registration Code: S-A 00018

Bridges on Çanakkale Highway: extraordinary solutions for extraordinary seismicity

M. Sartori(1), C. Galbiati(2), M. Ambor(3), G. Bresaola(4), S. Barone(5), I. Zivanovic(6)

(1) Technical Manager, Freyssinet Product Company Italia, mauro.sartori@freyssinet.com
(2) Technical Dept. Manager, Freyssinet Product Company Italia, claudio.galbiati@freyssinet.com
(3) Technical Dept. Manager, Atlante, michal.ambor@freyssinet.com
(4) Project Engineer, Freyssinet Product Company Italia, giorgio.bresaola@freyssinet.com
(5) Project Engineer, Freyssinet Product Company Italia, stefano.barone@freyssinet.com
(6) Deputy Director, Tech Department, Freyssinet, ivica.zivanovic@freyssinet.com

Abstract

Çanakkale-1915 is the longest mid-span suspension bridge in the world and it is part of a mega-scale investment in transportation and infrastructure in Turkey. The bridge across the Dardanelle (Çanakkale) Strait carries a new highway connecting Europe and Asia and it will represent a new alternative to the Bosporus passage.

The approach bridges are seismically isolated with high-friction curved surface sliders to accommodate the high displacement demand while dissipating the seismic energy transmitted to the piers and foundations which otherwise would be very large and costly due to the extreme seismic excitation foreseen for that region. This paper gives a complete overview of the seismic isolation system of both Asian and European approach bridges. More than 70 isolators were designed and manufactured by Freyssinet.

In addition, two viaducts of the approaching highway will be presented, both equipped with viscous dampers to dissipate a huge quantity of energy and designed and tested for extremely high performances.

These structures represent an application of mega anti-seismic devices, with displacement capacity up to more than one meter and design velocity above one meter per second.

Keywords: Seismic Isolation, Curved Surface Sliders, High Friction Coefficient, Viscous Dampers

1. Introduction

Kınalı-Tekirdağ-Çanakkale-Balıkesir motorway is part of the big plan of investments made by Turkey to develop the country, connecting Europe to Asia. It is a 321 km-long motorway, with an 82 km section between Malkara and Çanakkale under construction. This motorway is strategic since it will be the first route in Turkey linking Europe and Asia outside Istanbul.

The construction of the motorway started on 18th of March 2017 in Çanakkale, on the 102nd anniversary of the Turkish naval victory during the Dardanelles Campaign of World War I and it is expected to open in 2023.

Çanakkale 1915 Bridge, connecting western Anatolia with East Thrace, will cross the Dardanelles strait by the longest mid-span suspension bridge in the world with its 2023 m long mid span and 318 m high towers. Two approaches will give access to the bridge from the two sides for a total length of 4608 m. The deck will carry six lanes (three in each direction) of motorway, together with two walkways on each side for maintenance.

In addition to the exceptional figures of the motorway and of the main bridge over the Dardanelles, Turkey is one of the most seismic countries in the world, with Anatolian fault crossing its territory. The fault is 1500 km long and its north branch reaches Çanakkale. Very strong earthquakes of the Turkish history, with more than 8 events above magnitude 7, make each construction project a challenge, that only extraordinary solutions are suitable to cope with.

Freyssinet group, with the specific solutions dedicated to seismic protection developed by its Technical Department, is able to meet the need of mitigating the earthquake solicitation to the structure. Two main examples are given in this paper for the approach viaducts of the main bridge and for two viaducts of the motorway.

The first example shows the seismic protection of the two approach viaducts, where base isolation with curved surface sliders (CSS) has been applied. The isolators were designed to support high vertical loads and seismic displacements and were tested at velocities above 1 m/s.

Other two viaducts of the motorway are then presented, both protected against earthquake by viscous dampers installed on abutments and able to dissipate a huge amount of energy, when subjected to the seismic excitation. Their exceptional performances were the outcome of the R&D carried out by Freyssinet group to help designers in finding the most efficient solutions.

2. ISOSISM® PS anti-seismic devices

2.1. Technical properties

The seismic design of the approach viaducts is based on consideration of three types of earthquake events, corresponding to different levels of earthquake hazard and defined according to the respective mean return period and the corresponding probability of exceedance during the design life of the bridge (Table 1).

The method follows a Performance-Based Seismic Design (PBSD) philosophy to the extent that distinct performance requirements are set for the three seismic events characterized by different probability of exceedance. The functional performance is prescribed in terms of the required post-earthquake service level and accepted levels of damage with regards to reparability. These are summarized in the rightmost column of Table 1.

Base isolation of the approach viaducts is obtained by the installation of curved surface sliders ISOSISM® PS supplied by Freyssinet with different characteristics as shown in this section of the paper. The layout of the devices for Asian and European approach bridges decks are shown in Fig. 1.

Load effects (i.e. reactions on devices) and relative movements of the deck are taken for each limit state as envelope results under three different load combinations: Characteristic Service Limit State (SLS), Frequent Service Limit State (SLS) and Structural Ultimate Limit State (ULS).

Table 1 – Seismic action and corresponding service performance level

Seismic event		**Return period**	**Service performance level**	**Damage performance level**
Functional Evaluation Earthquake (FEE)		145 years	immediate access	minimal damage
Safety Evaluation Earthquake (SEE)	accessible	975 years	limited access	repairable damage
	inaccessible			minimal damage
No Collapse Earthquake (NCE)	accessible	2475 years	limited access	repairable damage
	inaccessible			minimal damage

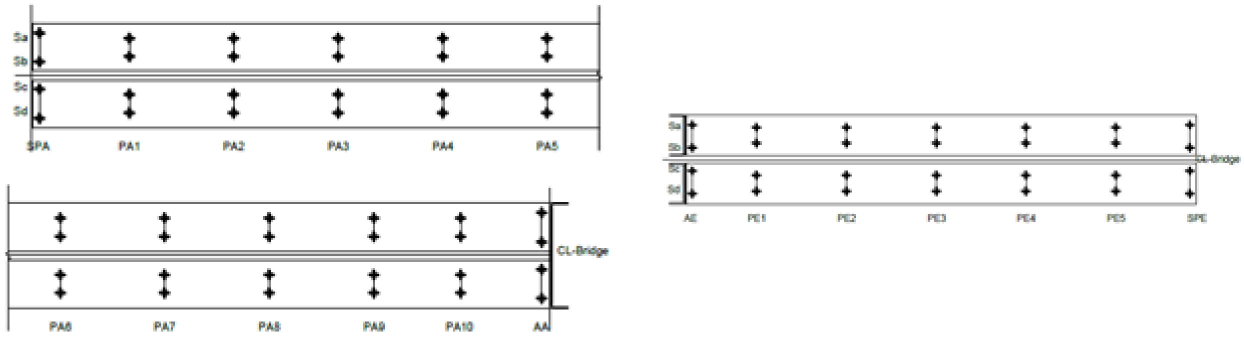

Fig. 1 – Layout of devices: Asian (left) and European (right) approach bridges

The seismic demand parameters of the devices are calculated through nonlinear time-history analysis taking the average of maximum values of 7-time histories for each earthquake return period. For the calculation of loads and movements in seismic events the results from the seismic time histories are combined with traffic loads. Long-term displacement due to permanent and quasi-permanent actions (e.g. post-tensioning, creep, shrinkage) and 50% of temperature effects (i.e. offset displacements) were also considered for the movements in seismic events. The maximum displacement demand of the devices and consequently their displacement capacity, is therefore determined by adding the potential offset displacements to the NCE seismic movement.

According to design loads and displacements at the supports, different ISOSISM® PS devices types were defined with uniform key properties; Table 2 and 3 report the main design characteristics of each device type for the Asian and European approach bridges, respectively.

Due to the high seismic displacement demand (more than ±600 mm) it was decided to provide CSS devices with double sliding surface in order to optimize the overall size of the isolators, as well as to halve the vertical load eccentricities transmitted by the devices to the piers during a seismic event.

The ISOSISM® PS devices are equipped with a special high-performance sliding material, named ISOGLIDE+®, that governs the energy dissipation produced by the dynamic friction coefficient between the sliding stainless steel surface and the sliding material. ISOGLIDE+® is a sliding material tested in accordance with European Standard EN 15129 and assessed by ETA. It is characterized by excellent wear (up to 10 km) and temperature resistance (up to 90°) and high compressive strength (up to 180 MPa).

Table 2 – Design loads and displacements: Asian approach bridge

ISOSISM®	**PS 17000/1700**	**PS 28000/1220**	**PS 28000/1300**	**PS 15000/1360**
POSITION	SPA	PA 1 5 7 8	PA 2 3 4 9 10	AA
number of devices	4	16	20	4
nonseismic vertical load N_{Sd} [kN]	6700	14175	13640	5400
max nonseismic vertical load $N_{ULS,max}$ [kN]	17000	28000	28000	15000
max seismic vertical load $N_{Ed,max}$ [kN]	12890	23924	23841	8545
nonseismic displacement d_{ns} [mm]	±254	±287	±256	±192
design displacement SEE d_{bd} [mm]	±635	±420	±450	±510
max displacement NCE d_{max} [mm]	±850	±610	±650	±680

Table 3 – Design loads and displacements: European approach bridge

ISOSISM®	**PS 15000/1680**	**PS 31500/1630**	**PS 31500/1540**	**PS 16000/2180**
POSITION	AE	PE 1	PE 2 3 4 5	SPE
number of devices	4	4	16	4
nonseismic vertical load N_{Sd} [kN]	6000	14250	14050	6550
max nonseismic vertical load $N_{ULS,max}$ [kN]	15000	31500	31500	16000
max seismic vertical load $N_{Ed,max}$ [kN]	10796	20868	26898	13154
nonseismic displacement d_{ns} [mm]	±208	±211	±222	±245
design displacement SEE d_{bd} [mm]	±570	±510	±525	±760
max displacement NCE d_{max} [mm]	±840	±815	±770	±1090

According to the distribution of vertical loads, different values of dynamic friction coefficients are defined, ranging from 4.4% to 5.9% (Table 4). All the devices are designed with an equivalent radius of curvature of 3700 mm. Fig. 2 shows the technical drawing of the ISOSISM® PS 16000/2180 (SPE support), the one with higher displacement capacity (±1090 mm).

Each deck of the approach bridges has two isolators at each support, except PA 6 on Asian side, where free sliding spherical bearings type TETRON® SB GL 30000.1150.1000 ($N_{ULS,max}$: 30 MN, $d_{max,long}$: ±575 mm) are used to allow the predicted displacements of the pier in longitudinal direction due to movement of the anchor block during both construction and service.

Table 4 – Dynamic frictional properties: Asian and European approach bridge

ISOSISM®	**PS 17000/1700**	**PS 28000/1220**	**PS 28000/1300**	**PS 15000/1360**	**PS 15000/1680**	**PS 31500/1630**	**PS 31500/1540**	**PS 16000/2180**
POSITION	SPA	PA 1 5 7 8	PA 2 3 4 9 10	AA	AE	PE 1	PE 2 3 4 5	SPE
$\mu_d(N_{Sd})$	5.4%	4.4%	4.6%	5.9%	5.4%	4.8%	4.9%	5.5%

Table 5 reports main global dimensions of all the devices of the project. All the devices have the high corrosion protection level type EN ISO 12944-2 C5-H and are provided of CE mark.

2.2. Testing

This section explains the Type Test (TT) and Factory Production Control Tests (FPCT) performed on the CSS devices according to EN 15129 requirements. The devices were tested at the University of California in San Diego. Fig. 3 shows the tests performed at CALTRAN testing facility, able to perform dynamic tests with longitudinal force up to 8900 kN, longitudinal displacement up to 1220 mm and maximum longitudinal velocity up of 1778 mm/s. Two prototypes of ISOSISM® PS 17000/1700 and ISOSISM® PS 31500/1540 have been tested under Notified Body witnessing, to qualify all the isolators for the project design specifications. The tests have been performed at the presence of the client and the construction manager.

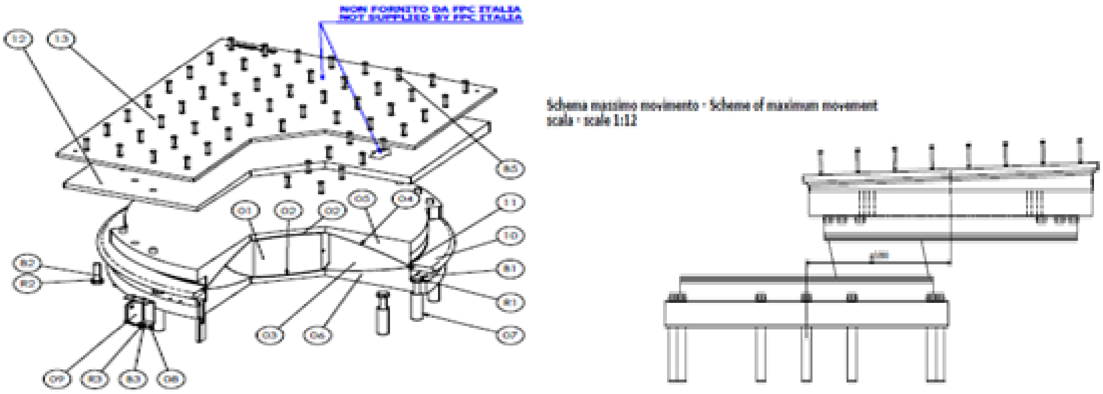

Fig. 2 – ISOSISM PS 16000/2180: technical drawing (left) and scheme of maximum movement (right)

Table 5 – Global dimensions of the devices

ISOSISM®	**Sliding plate plan dimensions [mm]**	**Total height [mm]**
PS 17000/1700	1760	360
PS 28000/1220	1580	275
PS 28000/1300	1615	295
PS 15000/1360	1365	240
PS 15000/1680	1645	320
PS 31500/1630	1890	380
PS 31500/1540	1860	375
PS 16000/2180	2140	535
TETRON® SB GL 30000.1150.1000	1780 x 1930	265

Table 6 shows the complete Type Test protocol for ISOSISM® PS 17000/1700 and ISOSISM® PS 31500/1540 respectively, to verify both sliding behavior and load bearing capacity.

Tests S, P1, D1, D2, D3, E1, E2, B and P2 aim to evaluate the dynamic behavior of the device in terms of friction coefficient (and therefore damping capacity), sliding stiffness and stability under repeated cycles. With these tests, the sliding behavior is fully characterized, identifying, and quantifying main sources of friction variability as velocity effect, pressure effect and cyclic effect. Finally, test BC is performed to verify the load bearing capacity of the device and the absence of any kind of damage and progressive flow or deterioration of the sliding material due to inadequate mechanical resistance, bonding, or confinement.

After the official TT were successfully completed on all devices, one ISOSISM® PS 31500/1540 was subjected to a sequence of additional tests aimed to verify the dynamic response under real bidirectional excitations with imposed displacements in both longitudinal and lateral direction (Table 7).

Test B1.1 was performed with the simultaneous application of a sinusoidal displacement input waveform to obtain a “clover leaf” path, while Test B1.2 input signal was a ground acceleration selected to match the total sliding path of official TT D3 test run. Clover leaf path and longitudinal and transversal components of the accelerations are shown in Fig. 4.

Fig. 5 shows the longitudinal force-displacement plots obtained for tests B1.1, B1.2 and D3. As it is possible to see, despite different input signals, since these tests were performed at the same vertical load, the friction value obtained is very close resulting in overlapped plots.

Factory Production Control Tests (FPCT) were performed at ISOLAB®, the innovative testing facility of Freyssinet Group, located in Montebello della Battaglia, Pavia (Italy). The Lab is equipped with test benches characterized by different capacities that allow testing in static and dynamic conditions according to

European and worldwide Standards. Fig. 6 shows the 70 MN dynamic press, the most powerful of the laboratory, which allows to perform static tests with vertical load up to 70 MN and dynamic tests with horizontal force up to 3000 kN, 1000 mm stroke and peak velocity up to 850 mm/s.

Fig. 3 – The CALTRANS Testing system

Table 6 – Type Test protocol according to EN15129

Test name [-]	Test run [-]	dof [-]	n [-]	PS 17000/1700			PS 31500/1540		
				d_{test} [mm]	v_{max} [mm/s]	N [kN]	d_{test} [mm]	v_{max} [mm/s]	N [kN]
Frictional Resistance	FR	hor	1	-	0.1	6700	-	0.1	14050
Service	S	hor	20	±254	5	6700	±222	5	14050
Benchmark	P1	hor	3	±635	50	6700	±525	50	14050
Dynamic 1	D1	hor	3	±159	1186	6700	±131	992	14050
Dynamic 2	D2	hor	3	±318	1186	6700	±263	992	14050
Dynamic 3	D3	hor	3	±635	1186	6700	±525	992	14050
Seismic 1	E1	hor	3	±635	1186	12890	±525	992	26898
Seismic 2	E2	hor	3	±635	1186	1032	±525	992	4064
Bidirectional	B	hor	3	±635	1186	6700	±525	992	14050
Property verification	P2	hor	3	±635	1186	6700	±525	992	14050
Load bearing capacity	BC	vert	1	-	-	13400	-	-	28100
hor = horizontal direction; vert = vertical direction; n = number of cycles									

Table 7 – ISOSISM® PS 31500/1540 additional test

Test name [-]	Test run [-]	dof [-]	d_{test} [mm]	v_{max} [mm/s]	N [kN]	n [-]
Bidirectional test – clover leaf motion	B1.1	hor - long	±525	992	14050	-
		hor - lat	±262	496		
Bidirectional test – displacement time history	B1.2	hor - long	±221	685	14050	-
		hor - lat	±144	418		

As prescribed by EN15129, FPCT must be performed on 20% of each CSS type; therefore, for this project, 8 devices were tested (one for each type). By example, Table 8 shows the FPCT protocol performed on ISOSISM® PS 31500/1630. These tests had the objective to verify the bearing capacity and frictional properties of the mass production. Test P1 was used as benchmark between FPCT and TT. For this project, the average friction coefficient obtained during three cycles was within ±20% of the reference value. The devices have positively passed all the acceptance criteria prescribed by the European Standard, thus obtaining the CE marking.

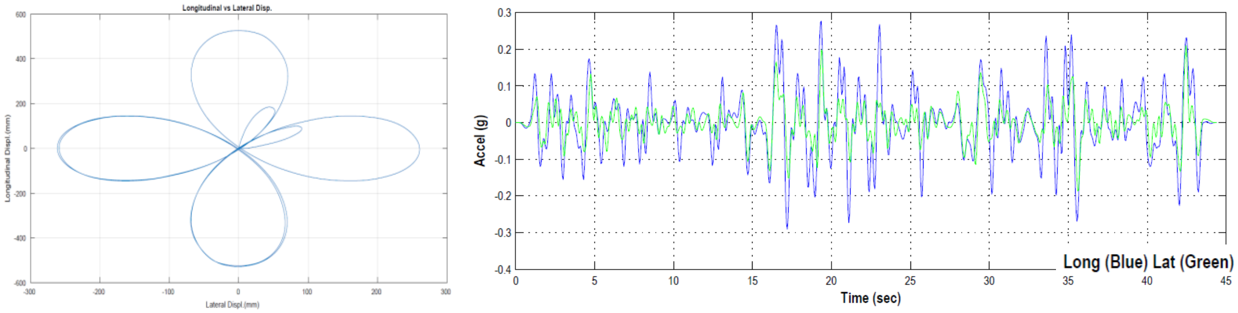

Fig. 4 – Test B1.1 and test B1.2. Longitudinal vs Lateral displacement

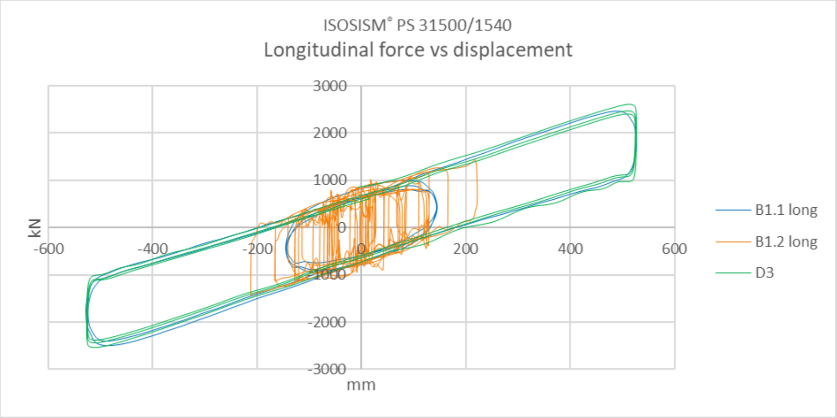

Fig. 5 – Test B1.1, B1.2 and D3 longitudinal force-displacement plot

Fig. 6 – The 70 MN ISOLAB® Testing system

Table 8 – ISOSISM® PS 31500/1540 FPCT protocol according to EN15129

Test name [-]	Test run	dof [-]	d_{test} [mm]	v_{max} [mm/s]	N [kN]	n [-]
Frictional Resistance	FR	hor	-	0.1	14250	1
Benchmark	P1	hor	±400	50	14250	3
Load Bearing Capacity	BC	vert	-	-	28500	1

3. V01 and V06 Canakkale Viaducts

3.1. Description

The complex of V01 and V06 viaducts represents a brilliant example of how the Freyssinet Group is able to offer, to its customers, a complete package from design to construction of a civil structure, proposing always avant-garde solutions to meet the technical and economic needs related to the structure itself. These viaducts, four in total, are part of the new Highway Kinali – Balikesir in Turkey, built in a highly seismic risk area. In detail, the V01 is located in Silivri District, while the V06 is in Malkara District.

The challenge of Freyssinet was to study and to present an alternative technical project for the structures, with the goal to improve the structure seismic response, to ease the construction method with reduction of the construction time and saving of the total construction cost of the viaducts.

Being a high seismic risk area, the technical concept of the viaducts had to obtain the best compromise between the strength characteristics of the structure and its ability to dissipate seismic energy, while guaranteeing the correct daily functionality of the structure in static conditions. The study, came up with the most advantageous technical proposal, for all the viaducts, developing a continuous prestressed concrete deck built through the incremental launching construction method, true strength of the Freyssinet Group (Fig. 7)

Fig. 7 - V06 viaduct under construction

The static scheme of the viaducts foresees the use of free and guided sliding spherical bearings type TETRON SB equipped with special sliding material ISOGLIDE®. The design choice to propose ISOGLIDE® sliding material, instead of a classic solution with PTFE according to EN 1337, allows on the one hand to minimize the friction, due to the vertical loads, and to reduce the overall external dimensions of the bearings, while on the other side allows to increase the wear resistance due to the accumulated path on the sliding material and the rotation capacity of the bearings. ISOGLIDE® has been tested up to 50 km of accumulated sliding path without showing any sign of deterioration.

In terms of seismic risk mitigation, the most efficient solution was to differentiate the dynamic behavior of the structure in the two main directions. In longitudinal direction, in correspondence of the abutments, a set of viscous dampers type ISOSISM® FD were provided, with very high mechanical and hydraulic performances, in order to dissipate a huge quantity of seismic energy and to avoid to overload horizontally the fixed piers of the viaduct. In transversal direction the transmission of the seismic forces from deck to piers is entrusted to the concrete shear key with energy dissipation in 4-shaft piers' plastic hinges.

The two viaducts have the same bearing layout (Fig. 8) characterized by central piers equipped with transversally guided CE-marked spherical bearing type TETRON SB GGT while other piers and abutments are equipped with free sliding CE-marked spherical bearings type TETRON SB GL. All spherical bearings have sliding surface with special sliding material ISOGLIDE®. Horizontal loads are transferred on abutments by longitudinal viscous dampers type ISOSISM® FD with CE mark and on piers and abutments concrete shear key. Table 9 shows the main bearings and viscous dampers characteristics.

3.2. Viscous dampers type ISOSISM® FD

The technical conception of the viaducts required the supply of 48 viscous dampers with extraordinary characteristics in terms of forces and velocities (Table 10), a big challenge for Freyssinet, who was in charge for the design, testing and supply of the viscous dampers (Fig. 9). The design and the testing of the viscous dampers were done following the requirements shown in the EN 15129 Chapter 7. In the Table 11, the main design data of the mechanical and hydraulic parts of the viscous dampers are shown.

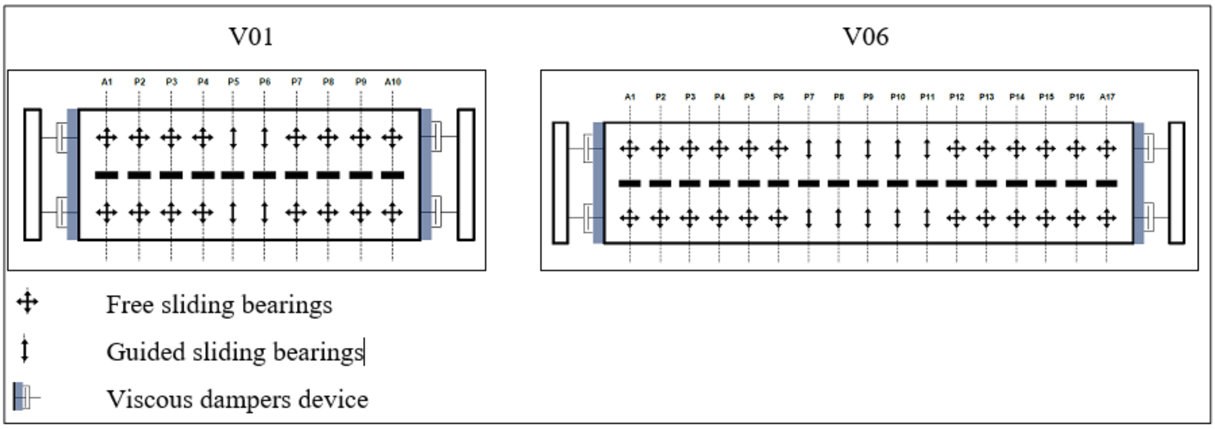

Fig. 8 – Bearing layout for V01 & V06 viaducts

Table 9 – Main figures of bearings and viscous dampers for V01 & V06 viaducts

VIADUCT	FREYSSINET Product Type	Pieces	Vertical load range [MN]	Horizontal load [MN]	Longitudinal displacement [± mm]	Velocity [mm/s]
V01	TETRON SB GL	32	10 to 23	--	335	--
	TETRON SB GGT	8	23	4	--	--
	ISOSISM® FD	20	--	3.57	310	790
V06	TETRON SB GL	40	10 to 23	--	427.5	--
	TETRON SB GL(-t)	8	23 (-1.4)*	--	410	--
	TETRON SB GGT	20	23	4.6	--	--
	ISOSISM® FD	28	--	3.57	462	1060

* Tensile force acting on the bearing

Table 10 – ISOSISM® FD required characteristics

VIADUCT	FREYSSINET Product Type	Force [kN]	Maximum seismic stroke [± mm]	Maximum velocity [mm/s]
PROTOTYPE	ISOSISM® FD 4000/1170	4242	340	1800
V01	ISOSISM® FD 4000/620	3400	310	790
V06	ISOSISM® FD 4000/925	3512	323	1060

Table 11 – ISOSISM® FD main design parameters

	PROTOTYPE	FD 4000/620	FD 4000/925
Maximum design force according to EN 15129 [kN]	5080	4090	4225
Pin to pin device length fully open [mm]	4980	3200	4200
Maximum internal fluid design flow [l/min]	14700	4800	6300
Design Energy dissipation for cycle EDC [kJ]	5599	4080	4390

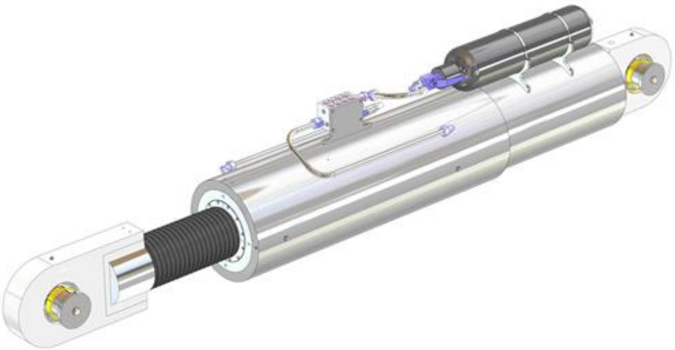

Fig. 9 – ISOSISM® FD - 3D view

Freyssinet Group believes in innovation and every year invests substantial resources in R&D to improve and increase its range of solutions. Since 2019, an important campaign has been run to enhance the capacity of viscous dampers for high loads, strokes and velocities. Tests performed at San Diego University on a prototype, properly manufactured, allowed to reach extraordinary performances up to the maximum velocity available at the testing laboratory. Main parameters of the prototype are shown in Table 10 and 11. The device was then positively tested according to the protocol of EN 15129 allowing to obtain the CE certificate for such huge characteristics.

The prototype test campaign was made in two different steps. A first one, performed at SISMALAB testing lab in Crispiano - Italy, with tests with velocity up to 500mm/s, and a second one performed at UCSD testing lab in San Diego - California, where the official test according to the protocol of EN 15129 chapter 7 (Table 12) was performed by the European Notified Body (Fig. 10)

Table 12 – ISOSISM® FD 4000/1170 - Type Test protocol and ISOSISM® FD 4000/925 - FPC test protocol

		FD 4000/1170 (TT)		**FD 4000/925 (FPC)**	
Type test according EN 15129	**N° of Cycles**	**Displacement (mm)**	**Velocity (mm/s)**	**Displacement (mm)**	**Velocity (mm/s)**
Seal wear	10000	±10	--	--	--
Low velocity	1 full	±10	0.01	±10	0.01
Constitutive law [1%]	3 full	±480	18	±323	11
Constitutive law [25%]	3 full	±480	450	±323	265
Constitutive law [50%]	3 full	±480	900	±323	530
Constitutive law [75%]	3 full	±480	1350	±323	795
Constitutive law [100%]	3 full	±480	1800	±323	1060
Damping efficiency test	3 full + 3 full	±480	1800	±323	1060

Fig. 10 - ISOSISM® FD 4000/1170 - Qualification test at USCD lab

The official test campaign was successfully concluded, satisfying all the acceptance criteria of EN 15129 and leading to obtain the CE mark on viscous dampers ISOSISM® FD up to 1.8m/s of velocity. Globally, the test results showed a stable behavior of the prototype for each level of the tested velocities. Moreover, no degradation in the behavior was observed during the cycles and the forces were in line with the expected values. Fig. 11 shows the results of constitutive law test and damping efficiency test.

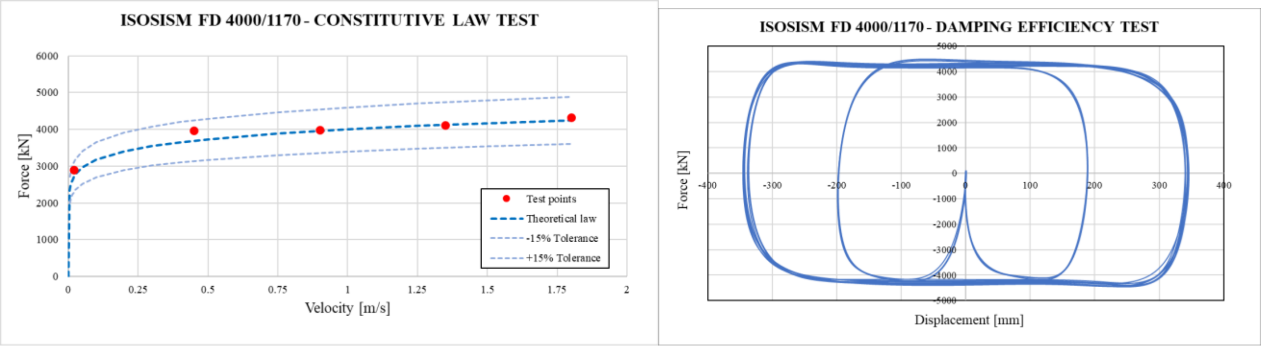

Fig. 11 – ISOSISM® FD 4000/1170 – Constitutive law test and Damping efficiency test

Following the validation of the behavior given the results on the test of the prototype, in 2020 the mass production of the 48 devices started (Fig. 12).

Fig. 12 – ISOSISM® FD 4000/925 during assembly phase

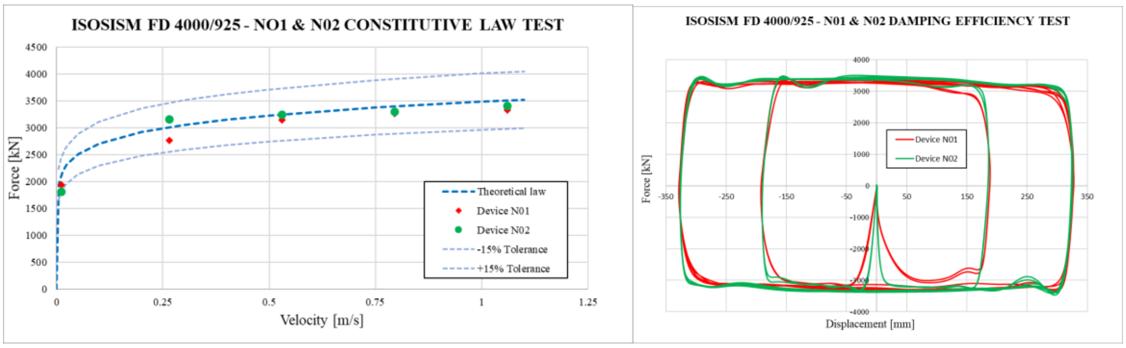

Fig. 13 – ISOSISM® FD 4000/925 N01 & N02 – Constitutive law test and Damping efficiency test

In June 2020 Factory Production Control tests were performed on the 5% of the mass production at the San Diego University laboratory because of the severe combination of load and velocity. Table 12 shows also the FPC tests performed on viscous dampers of Viaduct V06 ISOSISM® FD 4000/925.

For both devices, the test campaign was successfully concluded satisfying all the acceptance criteria of EN 15129. Globally, a very good repeatability was observed between the behavior of the two tested devices with excellent stability between cycles. (Fig. 13).

3.3. Spherical bearings

Continuous decks are supported by two bearings at each pier. Vertical forces on bearings reach a value of 23 MN in ULS and length of viaducts requires longitudinal sliding capacity at abutments reaching 850mm (+/-425mm).

At detailed design stage, a comparative analysis was performed between pot and spherical bearings technology for the provided set of forces. It was found that spherical bearings, thanks to the use of special sliding material Isoglide® not only turned out to be more competitive in terms of supply cost, but also led to significant savings in terms of space on the pier and weight for transport and handling. Result of the comparison analysis is shown in Table 13.

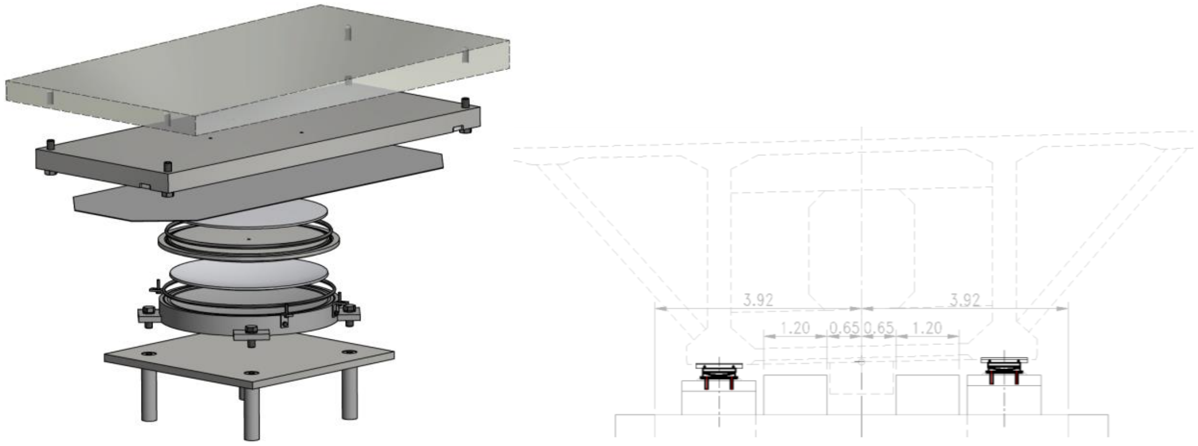

Fig. 14 – Spherical bearing 3D view and viaduct cross section

Table 13 – Bearing technologies

	Pot bearings	**Spherical bearings**
Rotation interface	Deformation of rubber disc confined in a steel "pot" and protected with anti-extrusion seal(s)	Steel spherical cap sliding on improved sliding material
Sliding interface	PTFE sliding material (as per EN 1337)	Isoglide improved sliding material (as per ETA 17/0808)
Critical factors for durability	Ageing and extrusion of rubber disc (depending on rotations magnitude and frequency) Wearing of sliding material Steel corrosion protection	Wearing of sliding material Steel corrosion protection
Cumulated sliding path wear resistance of the sliding material	10 km	50 km
Friction factor (temperature -10°C, under maximum ULS vertical force)	3%	2%

Bearing size reduction, when compared to pot bearings, allowed for space savings on the pier cap (Fig. 14), which geometry was highly congested due to presence of central concrete shear key, jacking points and all necessary space for operation of temporary launching (ILM) bearings.

Performance of delivered products was furtherly demonstrated through testing (Fig. 15) carried out at ISOLAB laboratory. Bearings were subject to Proof load test, Proof load test with concurrent rotation and Friction test. The last test showed a maximum friction coefficient not exceding 0.5%.

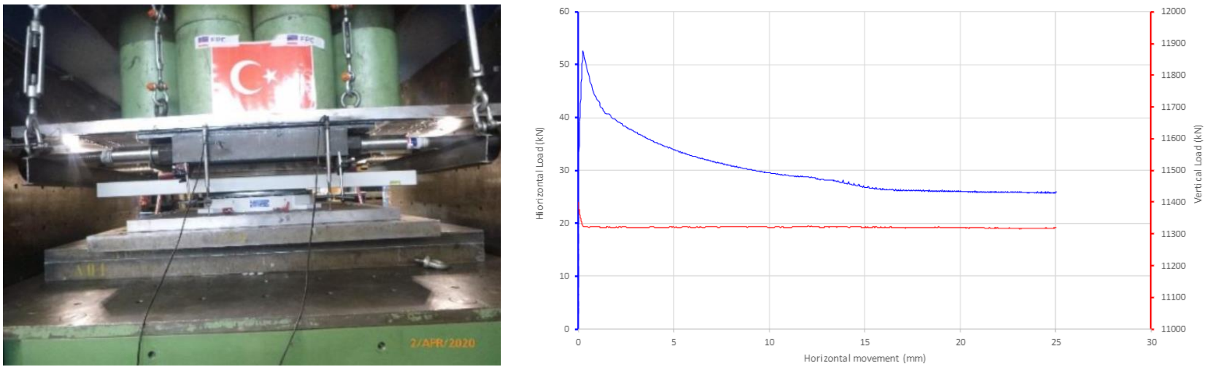

Fig. 15 – Spherical bearing test at ISOLAB and friction test result

4. Conclusion

Kınalı-Tekirdağ-Çanakkale-Balıkesir motorway represents an important investment for Turkish economy and allows people and goods to move through continents without barriers. It also represents for designers a challenge because of the major works needed and the influence of Anatolian fault on construction sites.

The paper presented different solutions to help designers in mitigating the seismic solicitation on the structures by means of the most recent techniques.

Two important case studies are given, showing the solutions that Freyssinet group can offer thanks to the strong effort spent in R&D from design to testing and from manufacturing to installation.

First, the base isolation of the approach viaducts of Çanakkale 1915 main bridge was presented, featuring curved surface sliders of huge dimensions and performances tested at the University of California - San Diego at extraordinary velocity.

Furthermore, two viaducts of the motorway supported by spherical bearings and protected against earthquake by enormous viscous dampers were described. These bespoke devices, installed on abutments, are able to dissipate a huge amount of energy. Their performance was proved at the University of California in San Diego at velocity higher than 1 m/s.